ESTIMATION OF WATER EROSION RATES USING RUSLE3D IN ALICANTE PROVINCE (SPAIN)

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ABSTRACT

The purpose of this study was the estimation of current and potential water erosion rates in Alicante Province using RUSLE3D (Revised Universal Soil Loss Equation-3D) model with Geographical Information System (GIS) support by request from the Valencia Waste Energy Use. RUSLE3D uses a new methodology for topographic factor estimation (LS factor) based on the impact of flow convergence allowing better assessment of sediment distribution detached by water erosion. In RUSLE3D equation, the effect that vegetation cover has on soil erosion rate is reflected by the C factor. Potential erosion indicates soil erosion rate without considering C factor in RUSLE3D equation. The results showed that 70% of estimated current erosion does not exceed 10 Mg ha^{-1} y^{-1} (low erosion). In the case of potential erosion rates, 16% of the area of Alicante Province does not exceed 10 Mg ha^{-1} y^{-1} but 33% exceed 200 Mg ha^{-1} y^{-1}. Based on these results, the current vegetation cover of Alicante Province is adequate but needs to be conserved to avoid an increase in the current soil erosion rates as shown by potential erosion rates.

1. INTRODUCTION

Water erosion is a severe and extended issue affecting all European countries, although with different intensities [1]. The European Mediterranean countries are particularly prone to erosion, because they are subject to prolonged dry periods, followed by heavy erosive rain falling on steep slopes characterized by fragile soils [1].

The process of soil erosion involves detachment, transport and consequent deposition. Sediment is detached from the soil surface both by raindrop impact and by the shearing force of flowing water. The detached sediment is transported downslope primarily by flowing water, although there is also a small amount of downslope transport by raindrop splash [2].

The Universal Soil Loss Equation, USLE, is the most widely used and accepted empirical soil erosion model for water erosion assessment. It was developed for sheet and rill erosion based on a large set of experimental data from agricultural plots [3]. In 1997, the Unites States Department of Agriculture (USDA) introduced the Revised Universal Soil Loss Equation (RUSLE) in the Agriculture Handbook No. 703 [4, 5]. USLE was developed for detachment capacity limited erosion in fields with negligible curvature and no deposition, and represents soil loss averaged over time and total area [6].

The use of USLE and its derivatives is limited to the estimation of gross erosion, and lack the capability to compute deposition along hillslopes, depressions, or in channels. Moreover, the fact that erosion can occur only along a flow line without the influence of the water flow itself restricts direct application of the USLE to complex terrain within GIS. This one-dimensional structure means that the equation cannot handle converging and diverging terrain, i.e., real 3-D landscapes [7].

With advances in Geographical Information System (GIS), erosion models tended to adopt a more explicit representation of the area on which erosion occurs using spatially distributed parameters, providing outputs showing the spatial variability of the process [8]. GIS-based approaches provide one of the few means available for systematically examining the role of spatial variability in soil properties, rock types and numerous other geologic and climatic properties in the evolution of a landscape. The spatially explicit nature of GIS analyses and the GIS emphasis on incorporating real-world data combine to make GIS a powerful tool for building insight into the evolution of complex landscapes and landscape processes [9, 10].

The objective of this study was the assessment of current and potential water erosion rates in Alicante Province with GIS support by request from the Valencia Waste Energy Use.

2. MATERIALS AND METHODS

2.1. Study Area

Valencia is an autonomous Region of Spain, located in the East side of the Iberian Peninsula, with 23,255 km^2 (8th

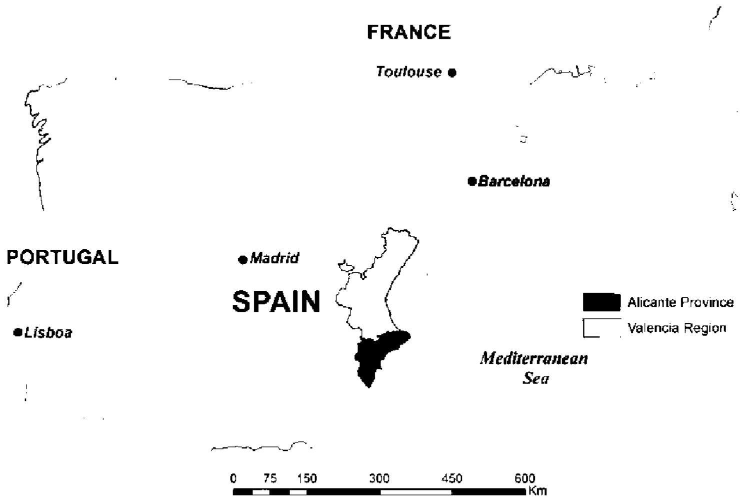


FIGURE 1 - Location of Alicante Province in Valencia Region (Spain).

largest region of Spain; Fig. 1). It is composed of the provinces of Alicante, Castellon and Valencia. It borders in the north with Catalonia and Aragon, in the west with Castilla-La Mancha and Aragon, and in the south with the Murcia Region. Alicante province is located in the South of Valencia Region (Fig. 1). The capital of the province is Alicante. The study area is approximately 5,818 km^2.

The principal geographic characteristics of the Region are the Ramblas (dry riverbeds or wadis) having water only during the rainy season. The mean annual precipitation is 340 $mm.yr^{-1}$. Their sediment discharges originate principally from erosion, and often these sediments are not massive.

2.2. Methods

The Universal Soil Loss Equation (USLE) by Wischmeier and Smith [3], and its current revisions, the Revised Universal Soil Loss Equation (RUSLE) and the Revised Universal Soil Loss Equation-3D (RUSLE3D) [5, 11], have been used all over the world in order to estimate the soil mean annual loss per area unit (T):

$$T = R \cdot K \cdot LS \cdot C \cdot P \quad (1)$$

where, R is the rainfall erosivity factor ($Mj.mm.ha^{-1}.h^{-1}.yr^{-1}$); K is the soil erodibility factor ($Mg.ha.h.ha^{-1}.Mj^{-1}.mm^{-1}$); L is the slope length factor; S is the topographic slope factor; P is the erosion control practice factor, and C is the cover-management factor representing the effects of vegetation management (LS; P and C factors are dimensionless). The C value is a ratio comparing the existing surface conditions at a site to the standard conditions [5]. Potential water erosion is soil erosion rate without taking into account the vegetation cover.

Specific effects of topography over the soil erosion are estimated by the one-dimensional factor LS, as the product of the slope length factor, L, and the slope steepness factor, S. As practised on the field, there is subjectivity in deciding exactly where to delimit boundaries for the subfield units of LS in RUSLE. The accuracy of where breaks for L and S values in a given farm field are located relies on the experience of the field operator partitioning the field into homogeneous LS units [12]. To minimize human subjectivity in estimation of LS factor, calculations based on digital elevation models (DEM) and GIS procedures have been developed, focused on a grid-cell based evaluation of LS factors in a multi-flow context [11, 13, 14]. Based on this concept, RUSLE model is named RUSLE3D (technique used in this study).

2.3. RUSLE3D Equation Factors. Spatial Modeling with RUSLE3D

2.3.1. Factor LS (L= slope length factor; S= slope steepness factor)

To incorporate the impact of flow convergence, the hillslope length factor (in USLE and RUSLE) was replaced by upslope contributing area (RUSLE3D) [15]. The modified equation, for computation of the LS factor in finite difference form in a grid-cell representing a hillslope segment, was derived by Desmet and Govers [13]. A simpler, continuous form of the equation for computation of the LS factor at a point $r=(x,y)$ on a hillslope, is [11]:

$$LS(r) = (m+1)\left[\frac{A_s(r)}{22.13}\right]^m \left[\frac{sen\ b(r)}{sen\ 5.143^{\circ}}\right]^n \quad (2)$$

where, the specific catchment area A_s (m) is the upslope contributing area, divided by the contour length which is assumed to equal the width of a grid cell of a raster layer; b is the slope in degrees; m and n are parameters for a specific prevailing type of flow and soil conditions; and 22.13 m is the length and 0.09 = 9% = 5.143° is the slope of the standard USLE plot [11].

LS factor estimation [16] was supported by GIS software, ArcGIS® 10 and GvSIG® [17]. The GIS GvSIG offers very significant advantages in terms of the hydrological analysis having several algorithms included to estimate slope inclination and flow accumulation, in comparison with ArcGIS. GvSIG is a free software, available in English and Spanish (http://www.gvsig.gva.es/).

To obtain the map with LS factor values and then integrate it into RUSLE3D, the following steps must be fulfilled:

I. Create a digital elevation model (DEM).In this case, using the ArcGIS algorithm, *TopoToRaster*, a 30-m raster layer was created from contour lines every 30 meters (Granted by Valencia Waste Energy Use).

II. Calculate slope inclination map.

III. Calculate flow accumulation map (upslope contribution area).

IV. Calculate specific catchment area map, A_s.

2.3.2. Rainfall Erosivity Factor, R

This factor represents rainfall power to erode soil surface, and is defined as the product of rainfall energy and maximum 30-min intensity.

Given the complexity presented by the calculation of this factor, there are various procedures for its determination, mostly based on regression analysis, where the variables are easily obtainable.

In a report of Roldan [18], a new equation has been made with high correlation coefficients and well-distributed residuals. The most important result of this work was an equation made specifically for Mediterranean climate. The advantage is that it only needs annual precipitation value to calculate the R factor (Eq. 3).

$$R_{annual} = 0.007 \times P_{annual}^{1.577} \tag{3}$$

From the precipitation data collected in Valencia Region, for the Spanish State Meteorological Agency from 37 rain-gauge stations (Fig. 2), Valencia Waste Energy Use, made a vector layer of annual mean precipitation points. For this research, that vector layer was used to create a raster layer (30 m grid cell) through the interpolation of those points.

The R values in this area range from 49 to 272.

FIGURE 2 - Location of rain gauge stations in Valencia Region, Spain (Source: Spanish State Meteorological Agency).

2.3.3. Soil erodibility factor, K

The K factor represents both susceptibility of soil to erosion, and the amount and rate of runoff. Soil texture, organic matter, structure, and permeability determine the erodibility of a particular soil [10, 19].

The dominant texture of these soils is sandy loam and the organic matter is about 5 %.

Due to lack of sufficient soil data the K factor was estimated using a research, performed in Valencia Region, by Garcia-Fayos et.al. [20], who related lithology and K values. A lithology vector layer was granted by the Spanish Geological and Mining Institute, in order to carry out this assessment.

2.3.4. Cover-management factor, C (non-dimensional)

The C factor is used to reflect the effect of the protection offered to the soil surface by the vegetative canopy, and the impacts of cropping and management practices on erosion rates [5].

When the effect of vegetation cover (C factor=1) is not taken into account in RUSLE3D equation, the result is the potential erosion rate. The potential erosion assessment shows the variation of soil erosion rates compared with current erosion rates. The resulting data layer should be viewed as a "worst-case" scenario, i.e. highest potential soil erosion of bare soil with no mitigating land use practices in place.

The data for the calculation of this factor was obtained from the Land Occupation Information System of Spain (SIOSE). SIOSE aims to integrate information from databases of land-cover and use from the Autonomous Regions of Spain. The SIOSE is part of the Spanish National Plan of Monitoring Territory (PNOT), which coordinates and manages the National Geographic Institute of Spain (IGN) and the National Center for Geographic Information of Spain (CNIG).

The main covers in Alicante province are facilities, forest, olive and fruit trees, scrublands, grasslands, wetlands and water. The mean C value is 0.15.

2.3.5. Erosion control practice factor, P (non-dimensional)

The P factor is the ratio of soil loss with a specific support practice (contouring, strip-cropping, terracing) to the corresponding loss with upslope and downslope tillage.

In this case, a value of 1 was assigned to P factor, because there is no data about conservation practice in the study area.

3. RESULTS

3.1. Current water erosion rates

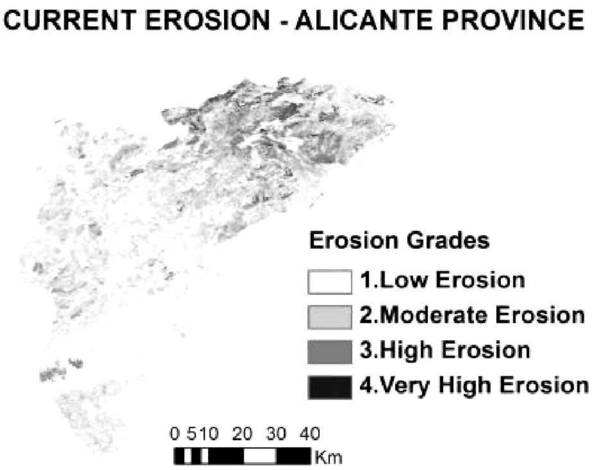
The main result from RUSLE3D model is that 70% of Alicante area does not exceed 10 Mg ha^{-1} y^{-1}, i.e., approximately 400,000 hectares of the area of the Alicante Province have minimal risk of erosion (Table 1).

TABLE 1 - Assessment of current erosion rates calculated with RUSLE3D in Mg ha^{-1} y^{-1}in Valencia Province.

	RUSLE3D	
Erosion Rates (Mg ha^{-1} y^{-1})	Area (%)	Area (ha)
Low Erosion (from 0 to ≤10)	69.3	403075
Moderate Erosion (from >10 to ≤50)	20.6	120011
High Erosion (from >50 to ≤200)	8.5	49208
Very High Erosion (> 200)	1.6	9553
Total	100,0	581847

TABLE 2 - Assessment of potential erosion rates calculated with RUSLE3D in Mg ha^{-1} y^{-1}in Alicante Province.

	RUSLE3D	
Erosion Rates (Mg ha^{-1} y^{-1})	Area (%)	Area (ha)
Low Erosion (0-10 t/ha.year)	15.4	89595
Moderate Erosion (10-50 t/ha.year)	22.6	131318
High Erosion (50-200 t/ha.year)	28.9	168131
Very High Erosion (>200 t/ha.year)	33.1	192804
Total	100,0	581847



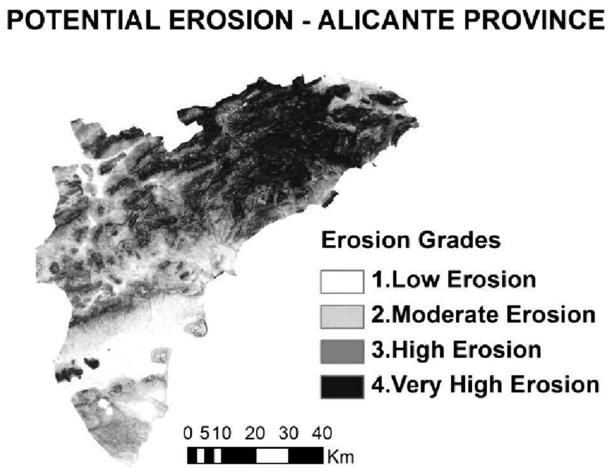


FIGURE 3 - Current and potential erosion maps of Alicante Province.

Another important fact is that 98% of the area of the Province does not exceed 200 Mg ha^{-1} y^{-1}, i.e., which is the lowest limit of the classification by FAO et al. [21] for "very high" erosion rates (Fig. 3).

3.2. Potential water erosion rates

In this case, the results show (Table 2) that, if the vegetation cover is not considered, 15% of the area of Alicante Province does not exceed 10 Mg ha^{-1} y^{-1}, and 33% exceed 200 Mg ha^{-1} y^{-1}, i.e., the highest level of risk of erosion (Fig. 3).

4. DISCUSSION

Some general remarks are necessary to mention in this section.

Regarding P Factor, it would be important to have more information about the existence of conservation practices in Alicante Region, such as vegetal waste covers or terraces. These types of practices lead to an improvement in infiltration and reduction of soil erosion.

In case of C Factor, due to the classification procedure used by SIOSE in order to identify land uses, is sometimes grouping two types of covers in a same tesserae, resulting in a bias in C value. For instance, in a tesserae where the C value should be zero, as in case of buildings or facilities, this does not occur as they are surrounded by crops or trees. SIOSE was used in this study because main Spanish institutions, including Valencia Waste Energy Use, apply it for land use identification in their own researches.

Nevertheless, it would be important for future assessment, especially if smaller areas are going to be studied, to improve vegetation cover data by setting single land use tesserae.

It is recommended to consider the different coverage stages of agricultural crops, bearing in mind that it is not constant throughout the year.

Finally, the assessment of soil erosion must be the first element to consider in a conservation plan. Erosion models like RUSLE3D, can predict the patterns of erosion in Valencia Region, and it can be used as a basis or guide for future land conservation practices in areas that require.

However, in order to make comparisons with other regions of Europe or even in Spain, it is necessary, like in Panagos et al. [22], to harmonise procedures, regarding models, parameters and sources of data.

5. CONCLUSIONS

RUSLE3D equation allows a more accurate estimation of the distribution of sediment removed by water erosion effects, and how the vegetation cover affects its assessment. Above all RUSLE3D factors, C and P are management factors, that is mean, any change in vegetation cover, affects directly on soil erosion rates.

The results from potential erosion assessment show that the absence of vegetation would generate a considerable increase in erosion rates. According to the current soil erosion rates, it can be concluded that the present vegetation cover of Alicante Province is adequate, and has to be protected and conserved in order to avoid the increase of soil erosion rates. Nevertheless, it is important to remark that field data is currently being collected in order to validate these results.

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